

Influence of Different Distances of Pecking Motion on Cyclic Fatigue Resistance of Reciproc Blue Files

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Abstract— The aim of the present study was to evaluate the influence of different distances of pecking motion (in-and-out axial movement) on the cyclic fatigue of Reciproc Blue files (VDW, Munich, Germany). Forty-two instruments were subjected to a dynamic cyclic fatigue test using a stainless-steel artificial canal with a 69° angle and 2.5-mm radius of curvature in a custom-made device that allowed the instruments to rotate freely inside the simulated curved canal in a reciprocating movement with different distances of pecking motion until fracture occurred. Fourteen instruments were tested in each group at three different pecking depths at a constant pecking speed of 2.5 mm/s: G(2.5): 2.5-mm depth, G(5.0): 5-mm depth, and G(7.5): 7.5-mm depth. The time to fracture and the number of cycles to fracture (NCF) were recorded. Data were analyzed using analysis of variance (ANOVA) followed by the post hoc Tukey test, with a significance level of 5%. The fracture surface of the fragments was examined by scanning electron microscopy. The results demonstrated that the time to failure and NCF significantly increased as the pecking distance increased. The mean time to fracture and NCF were significantly lower in G(2.5) compared to the G(5.0) and G(7.5) groups ($P < 0.001$). There were no statistically significant differences in the parameters between G(5.0) and G(7.5) ($P > .05$). The results show that different distances of pecking motion can significantly extend the life span of rotary files. Appropriate pecking motions in the root canals are recommended to prevent the breakage of nickel-titanium rotary instruments.

Keywords—Dynamic cyclic fatigue resistance. Instrument fracture. Nickel-titanium. Pecking motion. Reciproc Blue.

I. INTRODUCTION

Despite the advantages of nickel-titanium (NiTi) instruments, metal fatigue and subsequent breakage of rotary engine-driven files represent a potential problem during root canal instrumentation. NiTi files have been shown to fracture due to torsional failure or cyclic fatigue (KIM et al., 2012; PEDULLA et al., 2016; SILVA et al., 2018). Torsional fracture occurs when the tip of the instrument is locked in the canal while the shaft continues to rotate (WALIA et al., 1988; LOPES et al., 2011). Cyclic fatigue is the result of repeated compressive and tensile stresses accumulated at the point of maximum flexure in a curved canal, causing the metal's structure to break down and ultimately leading to fracture (PRUETT et al., 1997; PARASHOS et al., 2006).

The cyclic fatigue resistance of NiTi instruments increases significantly when operated in reciprocating motions compared to continuous rotation (PEDULLA et al., 2013). Furthermore, heat treatment of these instruments significantly improves their flexibility and resistance to fatigue (ZINELIS et al., 2007; GENERALI et al., 2019). Reciproc Blue NiTi reciprocating files undergo a specific thermal treatment that results in a visible thin blue titanium oxide layer on the surface of the files and increases flexibility and cyclic fatigue resistance (PLOTINO et al., 2014; DE DEUS et al., 2017).

Although some studies do not take into consideration the impact of environmental temperature in fatigue tests, it has been shown that an increase in temperature significantly influences the cyclic fatigue

behavior of NiTi instruments (PLOTINO et al., 2018; DE VASCONCELOS et al., 2016; DOSANJH et al., 2017). Tests performed at simulated body temperature reproduce the real behavior of instruments under clinical conditions. The manufacturers of NiTi instruments recommend their use with back-and-forth axial movement in the root canal. These movements during instrumentation give the instrument a longer time interval before it once again passes through the highest stress area and increases the time until fracture occurs (DEDERICH et al., 2017). Dynamic cyclic fatigue tests simulate the pecking motion performed by the operator under clinical conditions (ZUBIZARRETA-MACHO, et al., 2019).

The aim of the present study was to evaluate the influence of different distances of pecking motion on the dynamic cyclic fatigue of Reciproc Blue files at body temperature in simulated curved canals. The null hypothesis is that the distance of pecking motion does not significantly affect the time to failure or the number of cycles to fracture (NCF) of endodontic reciprocating instruments.

II. MATERIALS AND METHODS

The sample size was calculated a priori with the G*Power 3.1.9.2 software (Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany). Three groups (n=14) were formed to obtain a power of 80% and an alpha error probability of 0.05. Fourteen instruments per group (G) were tested at three different pecking depths (in-and-out movement): G(2.5) 2.5-mm depth, G(5.0) 5-mm depth, and G(7.5) 7.5-mm depth. A constant back-and-forth speed of 2.5 mm/s was used in all groups. Under an optical microscope (Alliance, São Carlos, SP, Brazil), each instrument was inspected at 25x for defects or deformities before the experiment and none of them was discarded.

Forty-two Reciproc instruments (Reciproc Blue R25) with a .08 taper and 25 mm in length were tested in a simulated canal, notched in the stainless-steel metal block. The canal was 24.8 mm long and 3.5 mm deep, with a straight cervical segment of 9.0 mm, 2.5 mm radius of curvature, 69° angle of curvature, a curved 2.15-mm long segment, and a straight apical segment of 13.3 mm. The canal was 2.0 mm wide in the widest coronal portion, tapering to 1.0 mm in the narrowest apical portion (Figure. 1). The canal was covered with an acrylic plate to prevent the instruments from slipping out and to visualize the rotating files. A synthetic oil (Super Oil, Singer Co Ltd, Elizabethport, NJ) was applied to reduce friction of the file as it touched the artificial canal walls.

A customized dynamic cyclic fatigue testing device was used in this study. A stainless-steel metal block with the artificial canal was positioned vertically on a hotplate stirrer (Fisatom, São Paulo, SP, Brazil). The temperature inside the simulated canal was measured with a laser thermometer (MT-320 Minipa, Joinville, SC, Brazil) and was kept constant at $36 \pm 1^\circ\text{C}$. The temperature inside the canal and synthetic oil was controlled with a digital infrared laser thermometer (Qingdao Tlead International, Shandong China) pointing into the canal. This temperature confirmation was performed for each file to be tested.

The instruments were coupled to a 6:1 reduction handpiece (Sirona Dental Systems GmbH, Bensheim, Germany), which was aligned to the axis of the artificial canal and powered by a torque-controlled motor (Silver Reciproc; VDW, Munich, Germany) using the preset program "RECIPROC ALL" as recommended by the manufacturer. The handpiece was fixed in a mobile unit powered by an electronically controlled servomotor (SAVOX SC-12 56T69; Savox, Taichung, Taiwan) to allow a precise and reproducible continuous up-and-down pecking movement of each file inside the artificial canal.

The instruments were inserted 22 mm into the simulated canal; a silicone stop was placed on each instrument to ensure that depth. The mechanical system of axial movement was activated and immediately exerted a retraction movement of 2.5 mm (G-2.5), so that the file was inserted 19.5 mm in the metallic canal (initial position), immediately the file started the axial movement 2.5mm forward and 2.5 back, simultaneously the instrument started the reciprocating movement. For the G-5.0 and G-7.5, the mechanical system exerted 5.0 or 7.5 mm of retraction movement, respectively, so that the file was inserted 17 mm or 14.5 mm deep in the canal (starting position), respectively, and started a 50 mm forward and 5.0 mm backward on the G-5.0 and 7.5 mm forward and 7.5 mm backward on the G-7.5.

To ensure accurate analysis of the time to fracture, video recording was performed simultaneously to determine the time (in seconds) from the beginning of instrument rotation to the exact time when fracture occurred. The NCF for each instrument was calculated by multiplying the time to failure (seconds) by the rotational speed (rpm), divided by 60. A rotational speed of 300 rpm was used following the manufacturer's instructions. For each instrument, the time to fracture was recorded and the experiment was interrupted when fracture was detected visually and/or audibly.

The fractured surfaces were analyzed under a scanning electron microscope (6360LV Scanning Electron

Microscope; JEOL, Tokyo, Japan). The instruments were arranged horizontally to identify plastic deformation, and the cross-sectional area of the fractured segment was analyzed to verify the fracture pattern of the instruments in each group.

Statistical analysis

The NCF and time to failure were compared between groups by one-way analysis of variance followed by the post hoc Tukey test (SPSS for Windows 19.0; SPSS Inc., Chicago, IL), adopting a significance level of 5%.

III. RESULTS AND DISCUSSION

The mean time to fracture is shown in Table 1. The statistical tests showed a significant difference in fracture time when different pecking distances were used. The time to fracture increased with increasing pecking distance. The cyclic fatigue resistance was significantly lower in G(2.5) compared to the other groups, with a mean of 32.5 seconds ($p < 0.001$). No significant difference was found between G(5.0) and G(7.5), which exhibited a mean time to fracture of 46.29 and 48.43 seconds, respectively.

The mean NCF values are given in Table 2. No significant difference was found between the two groups with longer pecking depths [G(5.0): 231.43 cycles and G(7.5): 242.14 cycles]. However, the NCF was significantly lower for the short pecking depth [G(2.5)], with a mean number of cycles of 162.5 ($P < 0.001$).

Scanning electron microscopy analysis

The SEM images of the fracture surfaces showed similar and typical features of cyclic fatigue, including ductile morphological characteristics on the fractured surfaces of all instruments and no plastic deformation in their helical shafts (Figure 2).

When NiTi rotary and reciprocating instruments are introduced into a root canal, an in-and-out axial movement is required to prevent locking of the file tip and torsional breakage (PALMA et al., 2019). The amplitude of an individual pecking motion may vary from professional to professional with load variations. The present results indicate that the pecking distance (in-and-out movement) is another factor that determines the resistance of rotary NiTi instruments to cyclic fracture, as well as temperature and angle of curvature.

In this study, an artificial canal with a radius of curvature of 2.5 mm and a severe (SCHEINEIDER, 1971) curvature angle of 69° in the cervical region was used, simulating a condition that can be found in clinical practice (CONSTANTE et al., 2007). Constante et al

observed that, although most mesiobuccal canals of mandibular molars are curved in the middle third of the root, the same proportion was found in the cervical and apical regions of the samples (24.64%). Estrela et al evaluated 1,200 root canals using CBCT and found that 73.25% had a curvature in the cervical third on coronal images.

The fatigue resistance of the files decreases as the environmental temperature increases (PLOTINO et al, 2018; DE VASCONCELOS et al, 2016). According to Hulsmann et al, fatigue resistance tests conducted at room temperature should be avoided. In the current study, dynamic cyclic fatigue of the instruments was tested at temperature $36 \pm 1^\circ\text{C}$, considering intracanal temperature $35^\circ\text{C} \pm 1^\circ\text{C}$ and body temperature of $37^\circ\text{C} \pm 1^\circ\text{C}$ (DE VASCONCELOS et al., 2016; DE HEMPTINNE et al., 2015).

To better simulate clinical situations, axial in-and-out movements with an amplitude of 2.5, 5.0 and 7.5 mm were performed in this study during the cyclic fatigue assessment. Similar studies have used axial movements ranging from 1.0 to 8.0 mm (KIM et al., 2012; DEDERICH et al., 1986; LI et al., 2002; RAY et al., 2007; LOPES et al., 2013; DE DEUS et al., 2014; OZYUREK et al., 2017; KESKIN et al., 2018; TOPÇUOĞLU & TOPÇUOĞLU, 2017).

The overall results of the present study demonstrated that pecking motion is an important factor to prevent the cyclic fracture of reciprocating instruments in curved canals and indicate that cyclic axial movement may significantly extend the life span of engine-driven files. The time to fracture and the NCF decreased significantly with decreasing pecking distance. Thus, the null hypothesis tested was rejected. The NCF and time to fracture were significantly smaller in G(2.5) compared to the longer pecking distances [G(5.0) and G(7.5)] ($P < 0.01$).

Cyclic fatigue fracture of the file occurs because of repeated compressive and tensile stresses accumulated at the point of maximum flexure in a curved canal (LOPES et al., 2013). Therefore, when longer in-and-out movements are used, the stress is distributed over a broader area throughout the instrument shaft within the curvature of the artificial canal (DEDERICH et al., 1986; LI et al., 2002), a fact that may explain the current results. On the other hand, in the case of shorter in-and-out movements, the stresses are concentrated in a small area of the instrument, which reduces the time to fracture and the NCF (DE DEUS et al., 2014).

Despite the inherent limitations of an in vitro study, the results obtained suggest that short back-and-forth movements should be avoided during root canal instrumentation, so that the stresses are not concentrated in a single area of the instrument. A longer pecking distance allows a longer time interval before the instrument once again passes through the highest stress area. This prevents the concentration of tensile and compressive stresses within the curved section, thus promoting stress distribution along a wider portion of the instrument and increasing the NCF (PALMA et al., 2019; LI et al., 2002).

IV. FIGURES AND TABLES

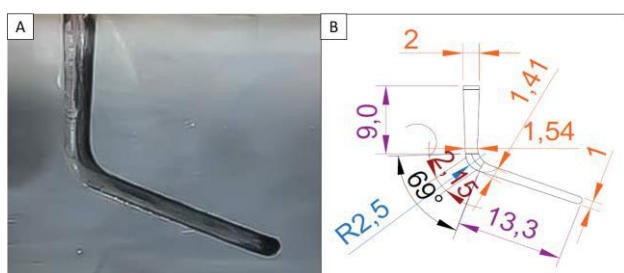


Fig. 1: (A) Stainless steel artificial canal used in the cyclic fatigue tests. (B) Geometric and dimensional characteristics of simulated curved canal.

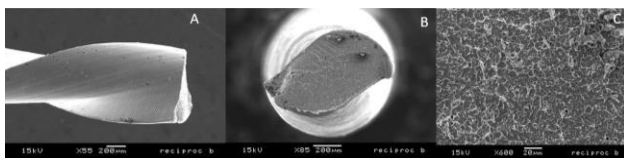


Fig. 2: Scanning electron microscopic analysis of the fractured surfaces of the tested instruments after cyclic fatigue test showing (A) no plastic deformation observed on the helical shaft (original magnification x 55) and (B, C) morphologic characteristics of the ductile type observed at the fractured cross sections (original magnification B x 85 and C x 600).

Table.1: The time to fracture in Seconds (Mean \pm Standard Deviation [SD]) of Different Groups with Different Pecking Distances

Distance	Mean	SD	Min – Max	p value
G2.5 mm (n=14)	32.50 a	10.04	17 – 51	<0.001
G5.0 mm (n=14)	46.29 b	11.29	33 – 76	
G7.5 mm (n=14)	48.43 b	10.39	32 – 65	

Max, maximum; Min, minimum; SD, standard deviation.

Different superscript letters in the same column indicate statistic differences among groups ($P < .05$).

Table.2: The Number of Cycles to Failure (Mean \pm Standard Deviation [SD]) of Different Groups with Different Pecking Distances

Distance	Mean	SD	Min – Max	p value
2.5 mm (n=14)	162.50 a	± 50.18	85 – 255	<0.001
5.0 mm (n=14)	231.43 b	± 56.45	165 – 380	
7.5 mm (n=14)	242.14 b	± 51.95	160 – 325	

Max, maximum; Min, minimum; SD, standard deviation.

Different superscript letters in the same column indicate statistic differences among groups ($P < .05$).

V. CONCLUSION

In conclusion, within the limitations of this study, the results suggest the use of a longer pecking distance during instrumentation of curved canals with reciprocating files. However, further in vitro and in vivo studies are necessary to confirm this suggestion. In addition, it would be necessary to have additional file systems being tested to show the effect of pecking distance is consistent across multiple brands.

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